CISTO*news*

Computational and Information Sciences and Technology Office

Sciences and Exploration Directorate, Goddard Space Flight Center

Winter−Spring 2008

Code 606 • http://cisto.gsfc.nasa.gov

IN THIS ISSUE

Contributors

Editor	Mike Hollis
Associate Editor	Jarrett Cohen
Website Design	Pamela Ricks
PDF Design	DeAnna Yu
Consultants	Lara Clemence Jim Fischer Jasaun Neff

NCCS Support of Space Exploration: Improving Space Weather Modeling Required for Interplanetary Travel

By Jarrett Cohen and Mike Hollis

Introduction

Within the next two decades, NASA will build a new generation of vehicles to return to the Moon and eventually make humankind's first trip to Mars. The Vision for Space Exploration is the driver for this overarching endeavor. Modeling and predicting the weather of the space environment that intrepid astronauts must traverse is a prerequisite for these journeys.

"If NASA plans to explore the Moon and Mars, reliably predicting space weather is essential," said Tom Moore, Deputy Director of the Heliophysics Science Division at Goddard Space Flight Center (GSFC). "If you were mounting an expedition to Antarctica, you would ignore the weather conditions at your peril. The solar system is the same, only worse. There are all kinds of powerful things going on in it."

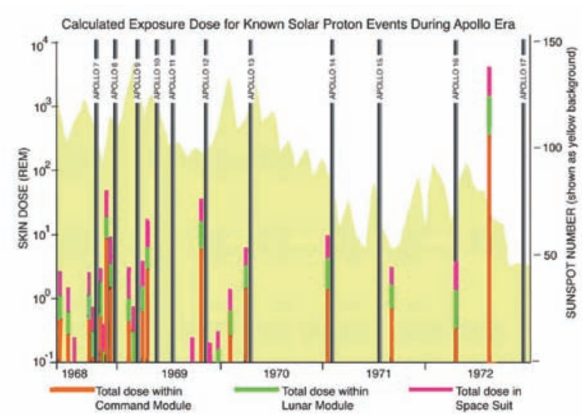


Figure 1: The graph shows the radiation dose to astronauts from solar events during the Apollo era missions, plotted against sunspot count. With longer-duration space flights planned as part of the Vision for Space Exploration, sporadic risks will become certain events. Figure from NASA's The New Science of the Sun-Solar System Connection: Recommended Roadmap for Science and Technology 2005–2035.

Among the hazards space travelers face are potentially lethal proton radiation events that emanate from solar storms. For example, Figure 1 shows radiation events during the Apollo missions to the Moon in terms of ionizing radiation dosage measured in Roentgen Equivalent Man (REM—the deposition of about 94 ergs of energy in 1 gram of soft body tissue). The radiation events are shown as orange, green, and pink bars. As established by the U.S. Nuclear Regulatory Commission for occupations in the nuclear field, the accumulative total dosage for an adult worker should not exceed 5 REM per year to be safe. Note that this limit does not nor cannot apply to astronauts! In any case, short, high-radiation events are more lethal than events of the same accumulated dosage spread out over a longer time span.

As Figure 1 shows, the astronauts were very lucky that most of their missions did not coincide with major solar events. An August 1972 event—right between the Apollo 16 and 17 missions—would have hit an astronaut with 300 to 3,000 REM of radiation! Note that 400 to 450 REM of whole body radiation in a short period of time would result in severe radiation poisoning and a 50 percent chance of fatality within 30 days. "It is mind-boggling that they were that close," Moore said. With a Mars journey taking months in each direction, NASA must have the capability to predict dangerous events and then provide safe haven for astronauts within the spacecraft.

NASA has a fleet of spacecraft designed to observe solar phenomena and space weather (see Figure 2). Moreover, the NASA Center for Computational Sciences (NCCS) is playing a vital role in the advancement of space weather modeling, which is really just in its infancy. With the problem ultimately involving the entire solar system, "we need all the supercomputing facilities that can be marshaled towards it, and there is probably no limit to the computing capability you could use," Moore said. The *CISTO News* staff interviewed three GSFC researchers heavily involved in improving various aspects of space weather modeling:

- In the near vicinity of the Sun, Joachim Schmidt investigates coronal mass ejections and their measurable effects at radio wavelengths using observations from spacecraft and ground-based telescope arrays.
- Inside the tail of Earth's magnetosphere, Alex Klimas models the evolution and interaction of magnetic reconnection sites in the plasma sheet—phenomena that can accelerate energetic particles towards our planet.
- Still closer to Earth, Tom Moore simulates the magnetosphere and ionosphere as they react to the solar wind and complicated solar events.

When perfected in NCCS exploratory runs, their techniques will migrate to production runs on the GSFC Space Weather Laboratory's computing cluster and improve predictions for the operational community. As they make progress, these computational explorers find that the NCCS is central to their research efforts. In the words of Moore, "We really treasure the NCCS!"

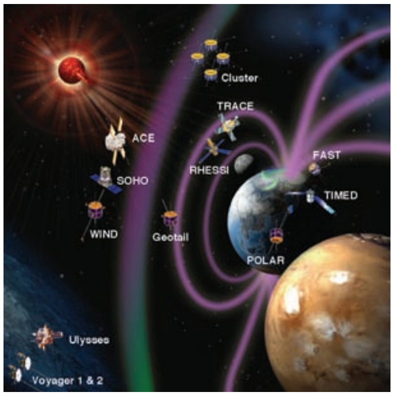


Figure 2: A fleet of spacecraft observe phenomena that emerge from the Sun and cause space weather. Data from these spacecraft aid NASA scientists using the NASA Center for Computational Sciences to improve space weather modeling.

Part I: Simulating Coronal Mass Ejections

A coronal mass ejection (CME) is a violent ejection of plasma—material comprised chiefly of protons and electrons—from the million-degree Kelvin solar corona just above the 6,000-degree Kelvin surface of the Sun. CMEs can propel up to 100 billion tons of material out into the solar system (see Figure 3 below). They tend to originate from active regions associated with sunspots on the solar surface. These regions have closed magnetic field lines that contain the plasma. Thus, the CME must open these field lines to escape from the Sun. When the CME ejecta reaches Earth, it can distort the magnetosphere (the region dominated by the planet's protective magnetic field), compressing it on the dayside and extending the nightside magnetotail. CME events can disrupt radio transmissions, cause power grid blackouts, and damage satellites.

Joachim Schmidt of GSFC's Planetary Magnetospheres Laboratory and others believe that the triggering mechanism for a CME is the movement of magnetic field lines and/or cancellation of magnetic footprint signatures

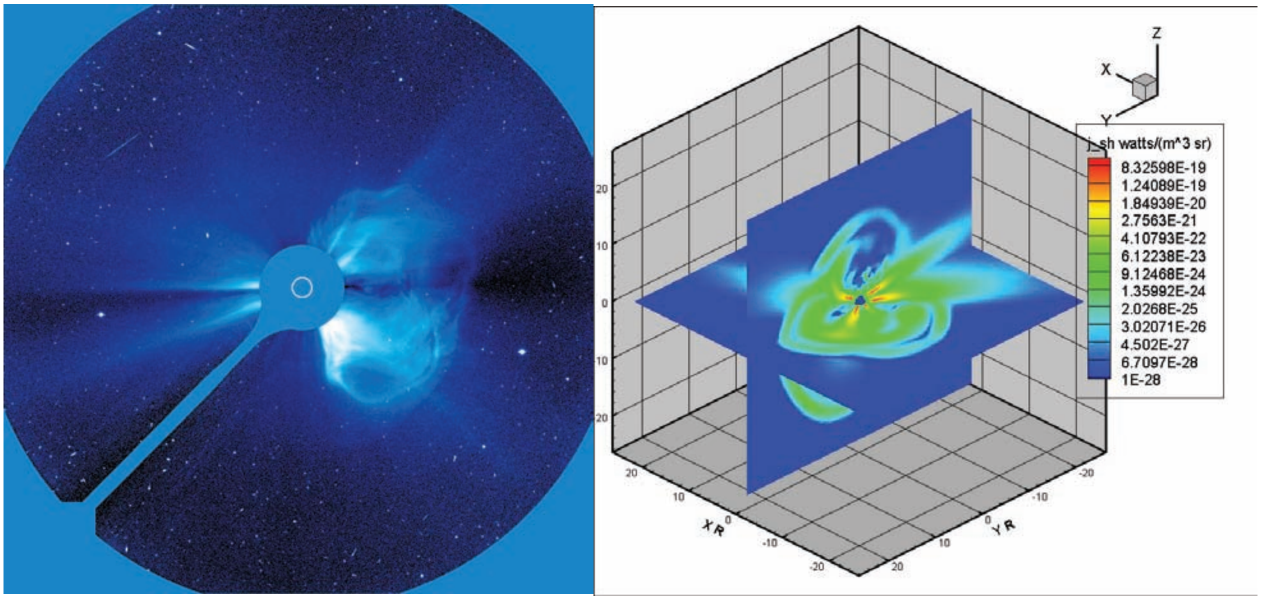


Figure 3: On the left is an image of a large coronal mass ejection (CME) taken by the Solar and Heliospheric Observatory (SOHO). The occulting disk blocks the Sun so that SOHO can observe the structures of the corona (the Sun's atmosphere) in visible light. The white circle represents the size and position of the Sun. On the right is a simulated 3D radiation map of the corona. Green coloring shows the radio radiation from a CME-driven shock, while jets colored yellow and red reveal the stream structure near the Sun. Simulation by Joachim Schmidt and Nat Gopalswamy.

directly below the coronal mass. Observations alone cannot distinguish between these scenarios because one only sees the resultant radiation at a distance. To theoretically model CMEs, Schmidt uses 128 processors of Explore, the NCCS' SGI Altix computer system. He attacks the problem by simulating a CME-driven collisionless shockwave on a large scale with one model and employing a second kinetic model that provides greater detail on a much smaller scale.

The large-scale model is a magnetohydrodynamics (MHD) computer code that solves MHD equations for the bulk motion of the outflowing plasma that can travel at speeds upwards of 1,000 kilometers per second. This code is the Solar Coronal module of the Space Weather Modeling Framework (SWMF) developed at the University of Michigan. The SWMF was initially funded earlier this decade by the NASA Computational Technologies Project within CISTO. The small-scale kinetic model code is one of Schmidt's design and is a continuing work in progress. Coupling these models provides three-dimensional (3D) predictions of the CME signatures in the radio region of the electromagnetic spectrum (see Figure 3), which can be validated by arrays of ground-based radio telescopes here on Earth and radio receivers on NASA vehicles such as the interstellar WIND spacecraft and the Solar and Heliospheric Observatory (SOHO).

Schmidt summarizes his major findings so far: "There were two schools of thought, that shockwaves that drive radiation dissipate very quickly or that they survive over large timescales and distances in space. I have determined that solar flares are much more dissipative compared to the much longer lived CME-driven shockwaves." As for future NASA exploration ventures, Schmidt is working with Joseph Lazio at the Naval Research Laboratory to design a dipole radio array for the Moon based on Schmidt's successful model results—a space weather station, if you will, for the Moon.

Part II: Focusing on Magnetic Reconnection

CMEs and other solar phenomena ride the solar wind that flows throughout the solar system. Earth is protected by its magnetosphere, a comet-shaped cocoon of magnetic fields connected to the planet. As described earlier, CMEs can distort the magnetosphere, extending its magnetotail. This extension ratchets up magnetic processes that are already a significant source for energetic particles harmful to space- and ground-based assets. Known as magnetic reconnection, these processes are the research subject of Alex Klimas, scientist in GSFC's Heliophysics Science Division.

From the Sun's interior to Earth's magnetosphere, magnetic reconnection can occur anywhere close-lying magnetic structures move towards one another, which brings nonparallel magnetic field lines into contact. Instabilities cause opposing field lines to merge and pinch off, forming entirely new configurations. Reconnection is small-scale (tens to hundreds of kilometers), making current observations extremely difficult, so computation is the best way to probe its intricacies. Klimas focuses on reconnection within a specific part of the magnetotail, a relatively thin plasma called the plasma sheet (see Figure 4).

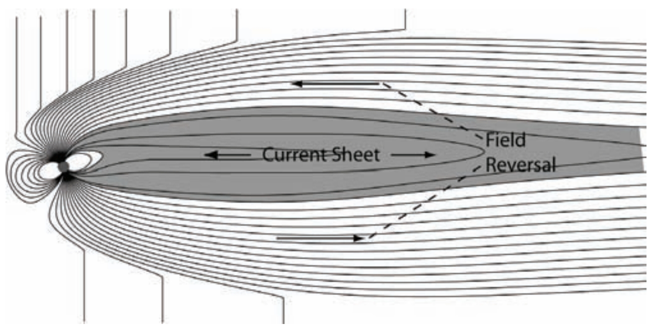


Figure 4: Simulations by Alex Klimas focus on a region of Earth's magnetotail called the plasma sheet . Inside this plasma sheet, magnetic field reversal (and magnetic reconnection) occurs along a complex, turbulent current sheet. Diagram by Alex Klimas.

This turbulent, highly dense plasma contains many reconnection sites that can interact and evolve into major events. Of particular interest are substorms. These explosive reconnection events accelerate energetic particles and other disturbances towards "the near-Earth region, where they produce nasty effects," Klimas said. Effects become magnified when substorms occur with solar magnetic storms.

Harnessing the NCCS' Explore supercomputer, "we're trying to understand how an avalanche of reconnection sites can occur," Klimas said. His unique approach allows the modeled plasma sheet to self-organize. The simulation continuously loads plasma and magnetic fields from the solar wind into the magnetotail and also lets them exit on their own. Over time, a plasma sheet forms and within it a current sheet separating magnetic fields in opposing directions. Next, reconnection starts in isolated spots, and the reconnection drives turbulence, which fuels more reconnection, and so on (see Figure 5).

"It is very exciting that we have gotten to this stage," Klimas said. "That is really our primary accomplishment so far, to make a code run long enough so that the model becomes stable enough for us to study the properties of reconnection and turbulence in the magnetotail."

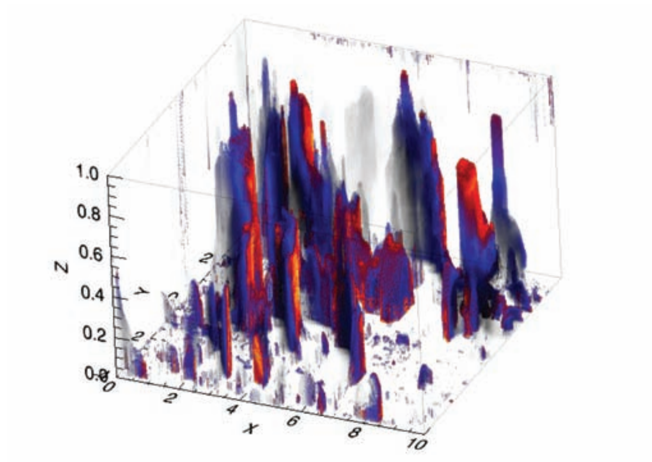


Figure 5: A simulation using the 3D Driven Current Sheet Model traces magnetic reconnection occurring in the top half of a plasma sheet within Earth's magnetotail. The redder the coloring, the more active the reconnection. Simulation by Alex Klimas and Vadim Uritsky.

Not surprisingly, a self-organizing simulation takes time. A single simulation with Klimas' 3D Driven Current Sheet Model using 16 processors needs months to come into proper equilibrium. The sheer scale of the plasma sheet—50 Earth radii wide by hundreds of Earth radii long—adds to the challenge. His 3D studies would have been impossible without an NCCS User Services programmer helping to speed up the code by a factor of 20. "Bless him; it was wonderful," Klimas said.

An earlier, 2D code remarkably matched aurora signals in the ionosphere observed by Polar and other spacecraft. Now poised to study the physical content with his 3D model, Klimas will be using data from several NASA spacecraft for statistical analysis.

Especially helpful are spacecraft that fly in the magnetotail, including Geotail, Cluster, and Time History of Events and Macroscale Interactions During Substorms (THEMIS). Guiding observation mission planning, results from Klimas' simulations are providing background support for the Magnetospheric MultiScale Mission (MMS). Scheduled for launch in 2015, MMS will have four spacecraft with detectors sensitive and fast enough to image magnetic reconnection sites in far more detail.

Part III: Getting the Ionosphere Model Right
Moving towards Earth, Tom Moore leads efforts to add greater realism to simulations of our planet's magnetosphere and especially its ionosphere, the top

atmosphere layer beginning 100 kilometers above the surface. The ionosphere has specific impacts on space exploration. It is the setting for magnetic and electrical disturbances that can interrupt space communications. Moreover, solar wind interactions with the upper atmosphere create dynamic changes that would make aero-braking reentry of a crew vehicle a challenging proposition—not only in Earth's atmosphere, but that of Mars as well. As NASA astronauts prepare to venture forth, it becomes more and more important to get the ionosphere's details right for space weather prediction.

"Current models don't allow the ionosphere to escape from Earth and circulate around, but in actuality it does," Moore said. It has been known for 30 years that the ionosphere "gushes out of the auroral zones," stealing as much as 300 to 400 tons per day from the atmosphere. Yet, modelers typically assume the ionosphere to be a thin, largely inactive layer. "Our job is to calculate how the ionosphere flows out and participates in the storminess going on around the planet," Moore said.

For accurate initial conditions, Moore's team drives simulations with observations of the upstream solar wind taken by NASA satellites. "We play games with what simple variations in the solar wind do to the system," he said. "Then, we use those results to interpret real events where you have a complicated time series of northward and southward turnings, rotations of the magnetic field, and gusts of the solar wind."
Describing how the ionosphere and magnetosphere react falls to single-particle calculations. Each virtual particle represents some larger number of real particles such as protons. Millions of these particles collectively act as a free fluid that can respond and expand. This fluid conducts electricity, and the currents distort and tear up the magnetic field.

These complex simulations have yielded several surprising findings. For one, it turns out that the escaping ionosphere fills the magnetosphere with plasma. This means that most of the plasma in the magnetosphere comes from the ionosphere rather than from the solar wind. "The old textbook picture that the solar wind comes in and lights up the aurora is completely wrong," Moore said. Some solar wind leaks in, but it is only about 1 percent of the plasma that hits the magnetosphere. The magnetospheric plasma usually contains comparable amounts of solar and terrestrial plasma, but at times the terrestrial plasma is much denser and especially more massive, because it contains oxygen.

Particularly when the ionosphere is buffeted by intense solar wind or southward-directed solar magnetic fields, hot plasmas from the ionosphere also inflate the magnetosphere. In what Moore calls "the self-

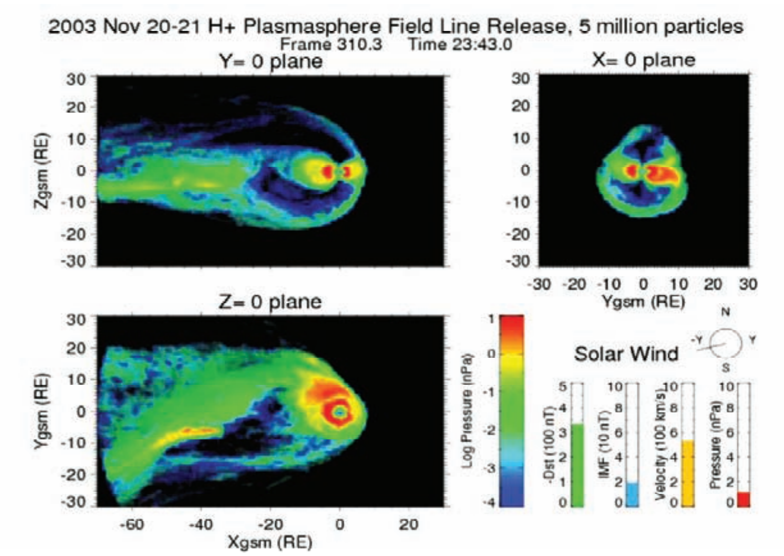


Figure 6: Recent simulations of magnetosphere-ionosphere interactions include the plasmasphere—a 2 Earth radii-wide ring of plasma located just above the ionosphere. Early results show the plasmasphere to be highly active during solar events. The panels show views in the Y, X, and Z planes, with colors indicating a log of the pressure in nanopascals. The vertical bars measure (from left to right) ring current magnitude, interplanetary magnetic field strength, and solar wind velocity and pressure. The compass-like circle traces solar wind direction. Simulation by Tom Moore, Mei-Ching Fok, Dominique Delcourt, Steve Slinker, and Joel Fedder. A spectacular movie of the simulation is available at: http://ipb.gsfc.nasa.gov/public/traj/dynamic-fields/Nov03_version12/plasmasphericWind/pressure.mpeg

inflating bicycle tube," ionospheric plasmas pump up the magnetosphere's peak pressure until it is 10 to 20 times the pressure that the solar wind exerts on it. "You end up with much more pressure trying to get out than the pressure with which the solar wind is blowing on the system," Moore said. "It is amazing."

The most recent addition to Moore's simulations is the plasmasphere, a ring of plasma located just above the mid- to low-latitude ionosphere. As he pointed out, NASA's Imager for Magnetopause to Aurora Global Exploration (IMAGE) mission reminded scientists that it is a very dynamic part of the magnetosphere. Early simulation results indicate the plasmasphere to be a "huge source of action" during solar events (see Figure 6 above on page 5).

Such multifaceted simulations require 128 to 256 processors of the NCCS flagship computer, the Discover Linux cluster. Even with teraflops of computing power, the team's simulations run slower than real time. Moore showed no concern, explaining that his team has two versions of their Global Ion Kinetic—Comprehensive Ring Current Model code. The NCCS version includes all the phenomena they can possibly model, while a "tuned-up, stripped-down version" does the best prediction it can faster than real time. The latter runs in the Space Weather Laboratory's Community Coordinated Modeling Center (CCMC), which is dedicated to research and development for the next generation of space weather models. "The more computer we can put in the CCMC, the more we can do in real time," Moore said. "The more computer we have elsewhere, the more research we can do on additional effects."

Epilogue

These investigations into the heliophysics of space weather are a small sample of the important research being conducted with NCCS resources. From Earth's interior to the far ends of the universe, NCCS users are tackling problems that cut across all divisions of NASA's Science Mission Directorate: Earth Science, Heliophysics, Planetary Science, and Astrophysics. Future *CISTO News* articles will showcase more of the key contributions computational scientists are making to these disciplines.

http://www.nccs.nasa.gov

http://hsd.gsfc.nasa.gov

http://nasascience.nasa.gov/heliophysics/mission_list

NCCS–SIVO Open House Features Computing and Service Upgrades

By Jarrett Cohen

On February 14, the NASA Center for Computational Sciences (NCCS) and the Software Integration and Visualization Office (SIVO) held a joint Open House that drew a standing-room only crowd. This extension of the quarterly NCCS User Forum meetings featured not only presentations but a demonstration of scientific visualization capabilities and a tour of the high-end computing facilities.

Open House attendees toured the NASA Center for Computational Sciences (NCCS) facilities, including the 2,560-processor Discover Linux cluster. Photo by Jarrett Cohen.

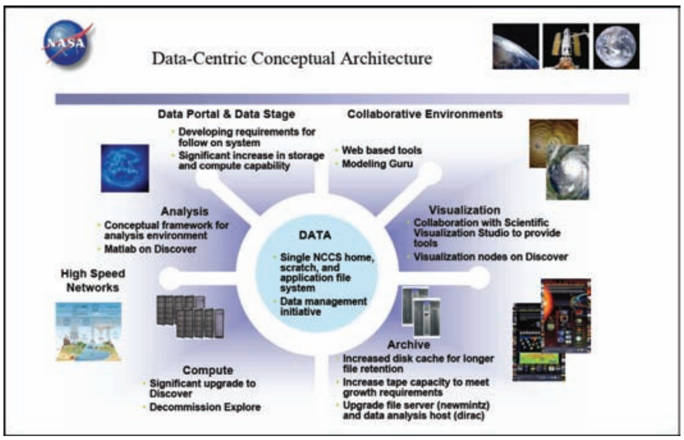
Phil Webster, CISTO Chief and NCCS Project Manager, and Mike Seablom, SIVO Head, provided overviews of the organizations and their partnership to support scientists and engineers throughout NASA's Science Mission Directorate.

Forthcoming NCCS hardware and software upgrades were highlights of the event. Most significant is a follow-on system to Explore, an SGI Altix 3700 system that will be decommissioned when its lease expires on September 30, 2008. As part of a 3-year technology refresh, a competitive acquisition is now in progress to yield the best price-performance. Regardless of vendor, the first stage of the upgrade will have roughly twice Explore's peak capacity, said NCCS Chief Architect Dan Duffy.

The Explore follow-on is being designed for consistency with the main NCCS compute platform—the Discover Linux cluster. Like Discover, the new system will use Intel Xeon processors of similar speed (2.67 to 3.0 GHz);

however, they will be quad-core rather than dual-core. The computer will have 2 gigabytes of memory per core, which is twice that of Discover and in keeping with Explore's larger memory. To minimize user disruption, there will be a 2-month overlap between the first upgrade stage and Explore decommission. The NCCS also will support users in migrating applications and data from Explore to Discover or the new system.

Additional NCCS computing environment enhancements planned for 2008 include Discover software upgrades (operating system, compilers, etc.), augmented scratch disk capacity, and a storage server upgrade.



NCCS hardware and software upgrades are being made in the context of a data-centric architecture.

Beyond traditional computing services, the NCCS provides a Data Portal for sharing results with collaborators without requiring NCCS user accounts, said Harper Pryor, CISTO Programs Development Manager. Soon after the Open House, the Data Portal's disk capacity was quadrupled to 120 terabytes. Moreover, using improved disk technology increases storage reliability, and adding more data paths between the portal CPUs and storage array boosts I/O performance.

In helping computing and data sharing users achieve their goals, the NCCS User Services Group is the first line of contact (level-1 support). Its members field questions about system use, code development, application support and make recommendations for optimal research throughput. SIVO's Advanced Software Technology Group (ASTG) provides level-2 support, including code porting, benchmarking, performance tuning, software engineering, and training. The latest training offering is a series of Fortran 2003 classes lasting through this spring, and ASTG may hold a "Boot Camp for Modelers" summer school.

Representing a new paradigm in level-2 support is Modeling Guru, a web-based "knowledge base" for NASA scientific modeling, said ASTG Head Tom Clune. Modeling Guru is currently in beta form at http://modelingguru.nasa.gov. It includes moderated discussions/forums, a document repository, and capabilities for submitting questions and support requests. All NCCS users will have logins by default, using their LDAP passwords. Anyone with relevant interest can request a login as well.

Scientific Visualization Studio Director Horace Mitchell listens to an attendee's question while showing visualizations on a nine-panel "hyperwall." Photo by Jarrett Cohen.

SIVO Scientific Visualization Studio (SVS) Director Horace Mitchell took attendees on an exciting journey through Earth and space science visualizations using both the main presentation screen and a nine-panel "hyperwall." The SVS is available for collaborations with NCCS users on developing visualization tools for communication, research and analysis, and operations.

The presentations concluded with SIVO's David Herring, Earth Sciences Division Education and Public Outreach Manager, describing efforts including NASA Earth Observations (NEO), Visible Earth, and the highly popular Earth Observatory. Attendees then departed for an NCCS facilities tour, led by Dan Duffy.

http://www.nccs.nasa.gov

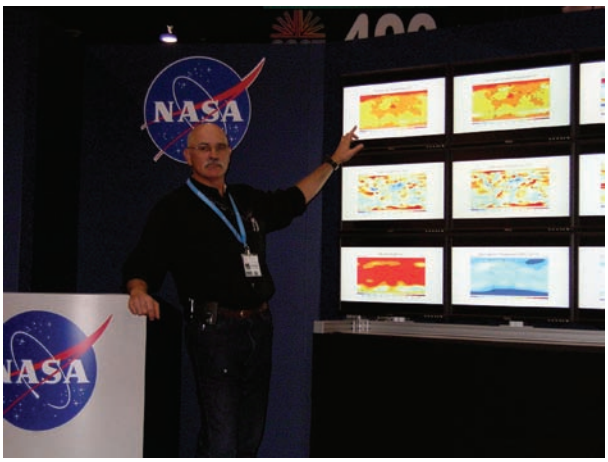
http://sivo.gsfc.nasa.gov

Nobel Prize-Supporting Work Among Highlights at Supercomputing 2007 Conference

By Jarrett Cohen

Nobel Peace Prize-supporting climate simulations were among the NASA achievements showcased at Supercomputing 2007, the International Conference for High-Performance Computing, Networking, Storage, and Analysis (SC07). The conference drew 9,250 attendees to the Reno-Sparks Convention Center, Reno, Nevada, November 10–16, 2007.

"NASA high-end computers are enabling simulations of the Earth's weather and climate with ever-increasing detail," said CISTO Chief Phil Webster. "Among this year's highlights, a NASA computer model simulated climate from 1880 through the present, and made projections of 21st century climate."



Using a nine-screen hyperwall in NASA's SC07 research exhibit, CISTO Chief Phil Webster shows movies of multiple fields from a Goddard Institute for Space Studies (GISS) ModelE climate simulation covering the years 1880 to 2100. Photo by Sally Stemwedel.

In the NASA research exhibit, Webster showed a selection of Goddard Institute for Space Studies (GISS) ModelE results on the nine-screen "mini-hyperwall," a traveling version of NASA's 49-screen hyperwall visualization tool. Model simulations generated using NASA Center for Computational Sciences (NCCS) supercomputers helped support the most recent assessment of the Intergovernmental Panel on Climate Change (IPCC), co-recipient of the 2007 Nobel Peace Prize.

Goddard Space Flight Center (GSFC) had record participation in the SC07 exhibit, with representatives from across the Sciences and Exploration Directorate and academic and industry collaborators.

Shown under the title "Global Climate Modeling: The Future of Our Planet," the GISS model results were the centerpiece of a three-part "GSFC Application Highlights" presentation. Parts 1 and 3 were "Mesoscale Dynamics and Modeling Group" by the Mesoscale Atmospheric Processes Branch and "Binary Black Hole Merger Simulations" by the Gravitational Physics Laboratory. Tom Clune, Lead, Advanced Software Technology Group (ASTG), Software Integration and Visualization Office (SIVO), gave the presentation as well.

The NASA exhibit's theater area also featured presentations by GSFC staff members and a university-based principal investigator:

- "Discover—NCCS Scalable Cluster," by Dan Duffy, Bruce Pfaff, and Mike Rouch of the NCCS.
- "From Remote Sensing to Global Simulation," by Horace Mitchell of SIVO's Scientific Visualization Studio.
- "Numerical Investigation of Young Stars," by Marina Romanova of Cornell University.
- "Technology Evaluations for Data-Intensive Computing at NASA Goddard," by Duffy.

A variety of demonstrations were shown at dedicated workstation stands throughout the exhibit:

- "3D Holographic Visualization Over SCinet & Beyond" by Pat Gary of CISTO's High-End Computer Network team, Ben Kobler of the NCCS and the Science Data Systems Branch, and Kirill Kolesnikov, David Bumjong Lim, and Alexander Naumov of Physical Optics Corp., a NASA Small Business Innovative Research partner.
- "Feasibility of IBM Cell Technology for Earth and Space Science," by Shujia Zhou of SIVO/ASTG.
- "High-Performance Computing for NASA Upper Troposphere Composition Research," by Brice Womack of SIVO/ASTG.
- "Numerical Modeling of Martian Historical Dynamo," by Weiyuan Jiang of the University of Maryland, Baltimore County.

http://sc07.supercomp.org

News Notes

NASA Debuts High-End Computing Website
On February 14, NASA's High-End Computing (HEC) Program officially launched its new website at:

http://www.hec.nasa.gov

The website serves as a gateway to the agency's two premier supercomputing sites, the NASA Advanced Supercomputing (NAS) Facility at Ames Research Center and the NASA Center for Computational Sciences (NCCS) at Goddard Space Flight Center. It is particularly aimed at guiding NASA-sponsored scientists and engineers through the processes of requesting computing time, getting accounts on HEC systems, and using systems at both facilities. The website also provides fundamental information about the program's mission, goals, and accomplishments, with overviews of computing resources and support services offered to NASA's Mission Directorates and collaborators nationwide.

For more information, contact Jarrett Cohen, HEC Program Information Officer, at Jarrett.S.Cohen@nasa.gov.

Best Paper Award
The NCCS' Carrie Spear (former employee) and Jim McGalliard received a Best Paper award at the Computer Measurement Group 2007 International Conference in San Diego, CA. Their paper, "A Queue Simulation Tool for a High-Performance Scientific Computing Center," describes a software tool that Spear developed to optimize the performance of NCCS Linux cluster systems. McGalliard presented the paper at the conference on December 3.